Coupled Multipath Congestion Control at Receiver in Content-Centric Networking

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***Abstract*—Content-Centric Networking (CCN), a recent innovative architecture, has brought about a great number of challenges for researchers whose ambition is to design such network with highly advanced ability to respond quickly to increasing demands from users. This receiver-driven content paradigm creates a different perspective of network. In this paper, we propose a coupled multipath congestion control at receiver in CCN which helps to enhance its capability of balancing congestion and network efficiency while remaining fair share among single-path user. The simulation results have shown that it can ameliorate the existing multipath algorithm for CCN.**

Keywords—content-centric network; receiver-driver; multipath congestion control; pull-based; interest control

I. Introduction

Since it was developed in 1980s, the Internet, which operates on IP network infrastructure, has become an essential part of modern world. As users demands are significantly growing, this may lead to its unsustainability. Several mechanisms have been proposed to improve network efficiency such as Content Delivery Networking (CDN) [1] distributing data to users based on their geographic locations. However, one of CDNs huge downside is that it is an application-designed executing on file-level or services, which causes difficulties in extending networks and high cost of maintaining on the long term. Therefore, a new network model derived on this approach has been proposed lately, called Content Centric Network [2]. CCN centers around the content, receiver does not need to know the exact address of where the content comes from, it only locates and routes content by unified content names. That explains why it is also called pull-based network.

In this paper, we present a multipath transport protocol at receiver in CCN, developed from Remote Adaptive Active Queue Management (RAAQM) [3]. RAAQM is the algorithm controls network congestion at its nodes, yet it may reduce fairness of the network if receiver is a multi-interface device that can transmit data simultaneously. Thus, we propose a multipath transport protocol at receiver in CCN, an algorithm that applies independent congestion windows management, and calculates Round Trip Time (RTT) for each path separately. This algorithm not only can utilize network resources and balance network congestion effectively but also maintain fair share among single-path user.

The following paper is structured as follows. Section II is a brief express of some related works. Then, we describe details of our algorithm in Section III. Simulation results attained from using CCNPL-Sim [4] are discussed in Section IV and a brief conclusion is in Section V.

II. Related Work

In several recent decades, there has been many research conducted on a name-based communication, controlled by the receiver, the so-called CCN. Data in CCN is split into data packets; each has an Interest packet with similar unified name. The ability to cache data at CCN router for reusing becomes one of its enormous advantages. The structure of this network was presented in [2]. Moreover, Yannis Thomas has designed an implementation of multipath receiver driven Transport Protocol for Information/ Content Centric Network [5]. Researchers of PARC recently has developed a name-based transport protocol for CCN which addresses some problems about distribution of content to users, mobility, and security for todays network [6].

In terms of network congestion control in CCN, the first algorithm was Interest Control Protocol (ICP) [7], which is based on Additive Increase Multiplicative Decrease (AIMD). ICP has proved that it can increase networks reliability and efficiency. Nonetheless, it only establishes a management mechanism for adjusting Interest packets, but not solve the issue of multipath in CCN. Inspired by ICP, Carofiglio et.al have proposed a multipath congestion control algorithm for CCN routers predicated on RAAQM and AIMD [3]. Although this algorithm helps to reduce overload of processing for end-nodes thanks to its distributed algorithm, it could adversely affect the fairness of network if receiver has more than one connections sending out requests concurrently.

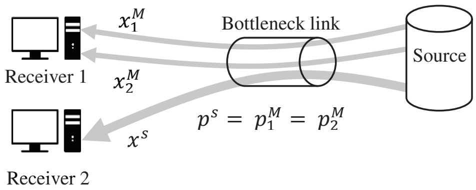

Fig. 1. Sharing bandwidth at a bottleneck link.

III. Design of Multipath Congestion Control Algorithm at Receiver

In this section, we propose a multipath transport protocol for receiver in CCN, but firstly is a summary of algorithm for single-path transmission.

A. Existing Single-path Congestion Control Algorithm

For each packet received, the algorithm increases the congestion window by μ/W. When timeout expires, the congestion window is decreased by $W/2$. During $\triangle t$ the window size is calculated as following equation

$$\frac{dW(t)}{dt} = \frac{W\left(t\right) - W(t-1)}{dt}. \tag{1}$$

At the equilibrium state, the increase and the decrease of window size are calculated as (2), and (3), respectively, where p is the packet loss probability.

$$\text{Increase: } x\left(\frac{\mu}{W}\right)(1-p) \tag{2}$$

$$\text{Decrease: } x\left(\frac{W}{2}\right)p. \tag{3}$$

When the increase equals to the decrease, we have

$$x\left(\frac{\mu}{W}\right)(1-p) = x\left(\frac{W}{2}\right)p. \tag{4}$$

We assume that packet loss probability is by far really small so $(1-p) \approx 1$. Therefore, x is calculated as $x = W/RTT$, then

$$x = \frac{1}{RTT}\sqrt{\frac{2.\mu}{p}}. \tag{5}$$

B. Design of Multipath Congestion Control Algorithm

Let denote i a sub-flow of source s which sends its data packets on path i. In order to satisfy the goal of fairly sharing, a parameter named θ_i is used which denotes the weight of source s on path i. The proposed algorithm at receiver in CCN controls its window size independently for each path. The window size of path i increases by $\theta_i\mu/W_i$ when receiving a return packet on that path. If congestion occurs it decreases by $W_i/2$. At the equilibrium state, we have

$$\frac{W_i\left(t\right) - W_i(t-1)}{dt} = 0. \tag{6}$$

Similarly, the value of x_i is calculated as following

$$\theta_i x_i\left(\frac{\mu}{W_i}\right)(1-p_i) = x_i\left(\frac{W_i}{2}\right)p_i. \tag{7}$$

Algorithm 1 Multipath algorithm for the receiver in CCN on path i.

```
alpha = 0.125
sRTT[i] = (1 - alpha)*sRTT[i]+ alpha*RTT[i]
X[i] = window[i] / xRTT[i]
sum_x = total(X);
if Receiver has multi-interfaces then
    theta[i]=(X[i] / sum_x)^2
else
    theta[i] = 1
end if
INCREASE_WINDOW()
REMOTE_AQM()/*Calculating probability of window decrease*/
function INCREASE_WINDOW()
    window[i] += theta[i] / window[i]
end function
```

$$\Rightarrow W_i = \sqrt{\frac{2\mu\theta_i}{p_i}}$$

$$\text{or } x_i = \frac{1}{RTT_i}\sqrt{\frac{2\mu\theta_i}{p_i}}. \tag{8}$$

Let x^S be rate of a single-path flow calculated as (4), $x^M{}_i$ be rate of path i calculated as (8). We then have

$$\sum x_i^M = x^S . \tag{9}$$

From (7), we have

$$p_i = \frac{2\mu\theta_i}{RTT_i^2 x_i^2}. \tag{10}$$

Because single-path flow and multi-path flow were competing in the same bottleneck link, $p_i = p$, $RTT_i = RTT\ \forall i$, substitute (10) into (9), we have

$$\sum x_i = \frac{1}{RTT}\sqrt{\frac{2\mu RTT^2 x_i^2}{2\mu\theta_i}} \tag{11}$$

$$\Rightarrow \sum x_i = \frac{x_i}{\sqrt{\theta_i}} \tag{12}$$

$$\Rightarrow \theta_i = \left(\frac{x_i}{\sum x_i}\right)^2. \tag{13}$$

The pseudo-code of the multipath congestion control algorithm at receiver is presented in Algorithm 1.

IV. Performance Evaluations

We evaluate the performance of this algorithm in terms of throughput improvement, fairness, and congestion balance with CCNPL-Sim [4]. Topology in Fig. 2 is used to investigate fairness at a single CCN node. To evaluate congestion balance and throughput improvement, we use Fig. 4.

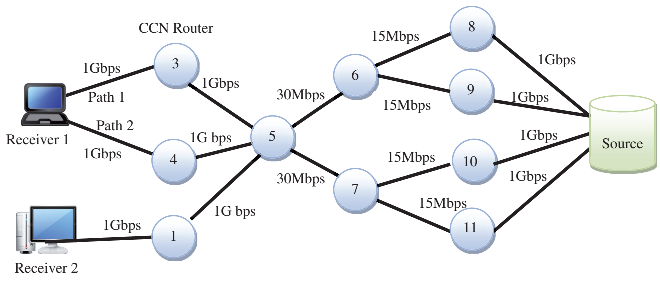

Fig. 2. Simulation topology for fairness.

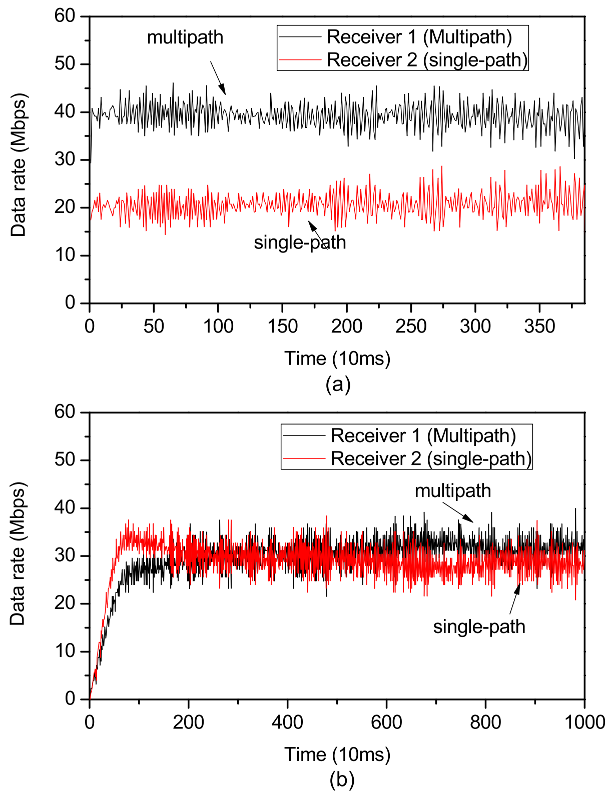

Fig. 3. Unfairness (a) vs. fairness (b).

A. Fairness

The topology in Fig. 2 includes 11 CCN nodes. Receiver 1 and Receiver 2 gets different content item with identical size and popularity at the same time. This allows us to obtain and objectively compare results of our proposed algorithm with multipath congestion control at CCN router algorithm [3].

Fig. 3 (a) shows two receivers' throughput of multipath congestion control at CCN router algorithm [3]. It is clearly seen that throughput of Receiver 1 is two-fold that of Receiver 2. The reason is because the receiver does not have multipath congestion control mechanism, which makes it to consider each connection of Receiver 2 as a single-path to CCN Router. Therefore, when sending Interest to CCN Router 5 two subflow's Interest rates are identical and each subflow'rate is equivalent to single-path's rate. So, the throughput of multipath connection is double that of single-path connection. Hence, providing that Receiver 1 (multipath user) has n connections, then its Interest rate will be n times higher than that of Receiver 2.
While Fig. 3 (b) plots our algorithm's results. Receiver 1 and Receiver 2 have approximate throughputs leading to the conclusion that they fairly share with each other. As proved in previous section, our algorithm proposed with θ_i at the receiver assures that Interest rate at multipath receiver is equal to that of single-path receiver when they compete at a single CCN node.

TABLE I. RESULTS OF CACHING AT CCN ROUTER.

	Three receivers download 3 different files.	Receiver 1 and 2 download the same file. Receiver 3 downloads another file.
Receiver 1	10.6214s	09.9535s
Receiver 2	22.0863s	19.3557s
Receiver 3	22.0013s	20.2287s

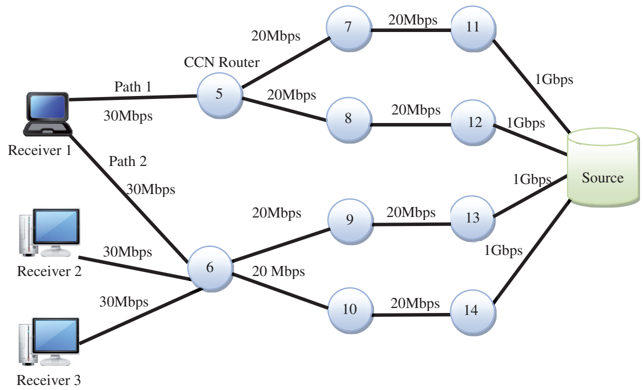

Fig. 4. Simulation topology for congestion balance.

B. Congestion Balance

The topology in Fig. 4 includes 10 CCN nodes,. Requested files have the same popularity, different content, and are large enough (30 MB in this experiment) to monitor results during a reasonable time. In Fig. 5 Receiver 1 requests data at time A, Receiver 2 requests at time B, and then comes Receiver 3. From time A to time B in Fig. 5, the throughput of Receiver 1 on path 1 and 2 are similar. From time B to time C, as Receiver 1 shares bandwidth with others so its throughput on path 2 considerably reduces. Additionally, we did two more experiments in which each requested file is 50MB in order to demonstrate CCN advantages.

We compare response time with the same content. Table I shows that the throughput of CCN is proportional to the popularity of content at CCN Router's cache. This means that every Interest packet once reaches CCN Router, data packets existing in CCN router's cache will be transmitted immediately to receiver without forwarding Interest packet to source. This is one of CCN's advantages compared to IP network. Also, it can be seen in that response time of Receiver 1 is two times smaller than that of Receiver 2 and Receiver 3. As a result, multipath connection outperforms single-path connection with regard to response time.

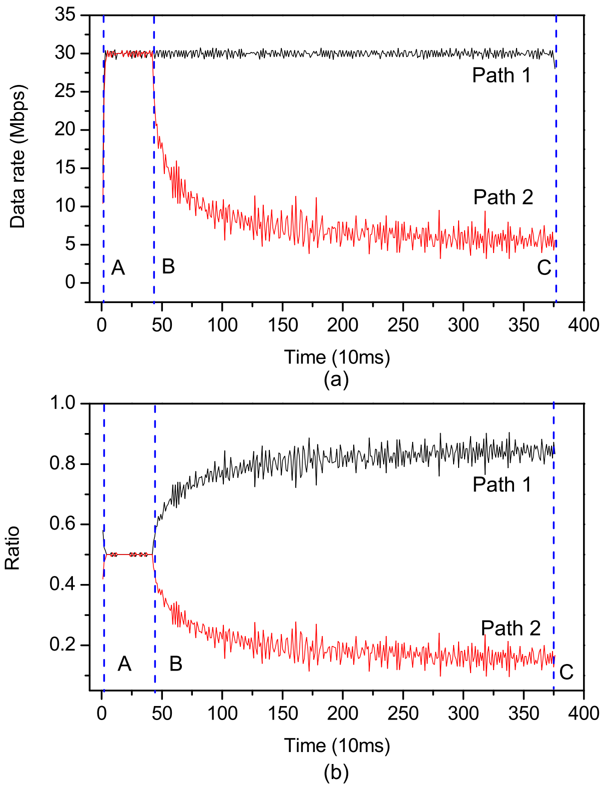

Fig. 5. Congestion balance.

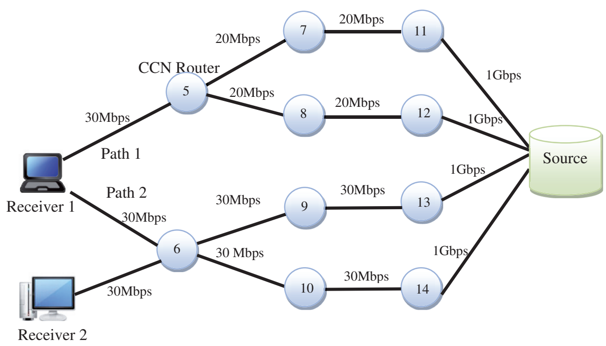

Fig. 6. Simulation topology for throughput improvement.

C. Efficiency

This section substantiates our algorithm's efficiency improvement in comparison with the congestion control algorithm at CCN router. To demonstrate throughput improvement, we use the topology in Fig. 6 with a single-path receiver. Both the single-path receiver and the multipath receiver try to download the same content with popularity of content. Fig. 7 shows that Receiver 1 with our multipath algorithm can send Interest packets on two separate paths. On path 1, Receiver 1 can obtain the whole bandwidth of 30 Mbps without any share. On path 2, Receiver 1 can also download at 30 Mbps. So, the total of throughput of Receiver 1 doubles that of Receiver 2 (single-path user).

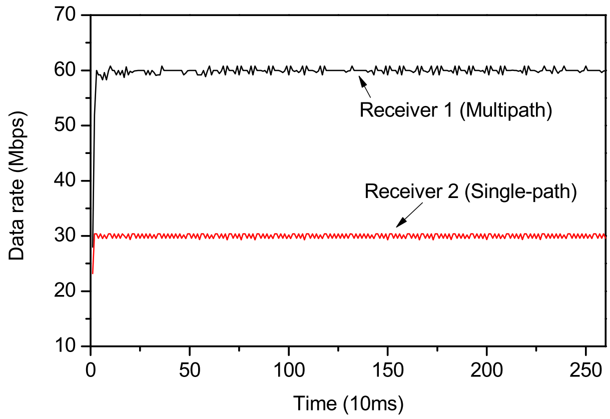

Fig. 7. Throughput improvement.

V. CONCLUSIONS

In this paper, we have proposed a multipath congestion control algorithm at receiver in CCN. Through simulation results, the proposed algorithm proves that it can resolve previous algorithm's disadvantages, enhances not only fairness, throughput but also congestion balance of network and efficiency.

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